CLAIMS

That which is claimed is:

1. A communications satellite system for providing communications between a plurality of mobile terminals and a satellite ground station, said system comprising:

at least one orbiting satellite comprising a satellite dual-polarization receiving antenna, said satellite dual-polarization receiving antenna comprising multiple satellite antenna elements that receive first and second polarized signals from said plurality of mobile terminals, wherein said first polarized signals correspond to a first one of said dual polarizations and said second polarized signals correspond to a second one of said dual polarizations;

a first transponder on board said satellite that processes said first polarized signals received from said mobile terminals to convert said first polarized signals to a first feeder link signal for transmission to said satellite ground station using a first feeder link polarization;

a second transponder on board said satellite that processes said second polarized signals received from said mobile terminals to convert said second polarized signals to a second feeder link signal for transmission to said satellite ground station using a second feeder link polarization;

a ground-station dual-polarization receiving antenna at said satellite ground station that receives said first and second feeder link signals, said ground-station dual polarization

receiving antenna comprising multiple ground-station antenna elements that receive said first and second feeder link signals from said satellite;

a dual-channel receiver connected to said ground-station dual-polarization receiving antenna that amplifies, filters, downconverts, and digitizes the received first and second feeder link signals to produce numerical sample streams corresponding to said received first and second feeder link signals received at each of said multiple satellite antenna elements and each of said dual-polarizations; and

a diversity demodulator connected to said dual channel receiver that combines said numerical samples streams to reproduce information transmitted by said plurality of mobile terminals.

2. The system of claim 1 wherein said satellite dual polarization receiving antenna is a Direct Radiating Array comprised of dual-polarization array elements.

3. The system of claim 1 wherein said satellite dual polarization receiving antenna comprises multiple dual-polarization antenna feed elements and a reflector.

4. The system of claim 3 wherein said multiple dual-polarization antenna feed elements are located out of the focal plane of said reflector.

5. The system of claim 3 wherein said multiple dual-polarization antenna feed elements are coupled using a Butler matrix.

6. The system of claim 4 wherein selected subgroups of said multiple dual-polarization antenna feed elements are coupled using Butler matrices of reduced complexity.

7. The system of claim 1 wherein said first and second transponders downconvert received signals from each of said multiple satellite antenna elements to the complex baseband to obtain corresponding In-phase (I) and Quadrature (Q) signals.

8. The system of claim 7 wherein said first and second transponders each use quadrature time-division multiplexing to multiplex said (I,Q) signals corresponding to the same polarization of different antenna elements to obtain a first and a second feeder link baseband signals.

9. The system of claim 8 wherein said first feeder link baseband signal is upconverted to a first feeder link frequency to obtain said first feeder link signal and said second feeder link baseband signal is upconverted to a second feeder link frequency to obtain said second feeder link baseband signal.

10. The system of claim 9 wherein said first and second feeder link frequencies are the same frequency.

11. The system of claim 1 wherein said numerical sample streams at said ground station comprise complex numerical samples having a real (Inphase or I) part sample stream and an imaginary (Quadrature or Q) part sample stream.

12. The system of claim 11 wherein said dual channel receiver uses quadrature time-division demultiplexing to demultiplex the signal from each channel to thereby obtain said complex (I, Q) numerical sample streams.

13. The system of claim 1 wherein said diversity demodulator combines said numerical samples streams using beamforming controlled by a number of complex beamforming coefficients.

14. The system of claim 13 wherein the number of said beamforming coefficients used at any instant is equal to the product of the number of said numerical sample streams times the number of signals from said plurality of mobile terminals received on the same frequency channel at said at least one orbiting satellite at said any instant.

15. The system of claim 13 further comprising a beamformer and beamforming coefficients corresponding to each of said dual polarizations.

16. The system of claim 13 wherein said beamforming coefficients optimize demodulation of information from each of said plurality of mobile terminals independently.

17. The system of claim 15 further comprising a separate demodulator for each signal simultaneously received on a given frequency channel from said plurality of mobile terminals that further combines outputs from said beamformers to decode information from one of said plurality of mobile terminals.

18. The system of claim 17 wherein said separate demodulator uses combining coefficients estimated with the aid of known symbols included in transmissions from said plurality of mobile terminals.

19. The system of claim 13 wherein said beamforming coefficients are fixed and correspond to optimizing reception from a set of fixed directions.

20. The system of claim 16 wherein said beamforming coefficients are fixed and correspond to optimizing reception from a number of fixed directions, and said plurality of mobile terminals are allocated to use a set of said beamforming coefficients corresponding to optimum reception from the direction in which each of said plurality of mobile terminals location most closely corresponds.

21. The system of claim 1 wherein said diversity demodulator comprises a separate demodulator and decoder for each signal received simultaneously on a given frequency channel from said plurality of mobile terminals.

22. The system of claim 21 wherein each of said separate demodulators jointly process information received in a timeslot allocated to one of said plurality of mobile terminals together with information received in a timeslot which is allocated to the same one of said plurality of mobile terminal in some TDMA frames and to a different one of said plurality of mobile terminals in other TDMA frames.

23. The system of claim 1 wherein said diversity demodulator combines samples corresponding to different satellite antenna elements, different polarizations, and different timeslots using weighting coefficients to optimize decoding of information received from each of said plurality of mobile terminals.

24. The system of claim 1 wherein said diversity demodulator is adapted to perform digital channel splitting to separate each of said numerical sample streams into numerical sample streams of reduced sample rate, each numerical sample stream of reduced rate corresponding to one of a number of frequency channels.

25. The system of claim 24 wherein said diversity demodulator further is adapted to perform digital beamforming for each of said frequency channels to combine ones of said numerical sample streams of reduced sample rate corresponding to the same frequency channel.

26. A communications satellite system for providing communications between a plurality of mobile terminals and a satellite ground station, said system comprising:

at least two orbiting satellites each comprising a multi-element, dual-polarization receiving antenna comprising multiple satellite antenna elements that receive signals from said plurality of mobile terminals, each of said satellites having a dual-channel transponder that transponds signals received by each of said multiple satellite antenna elements so as to preserve relative phase and amplitude between signals from different satellite antenna elements of the same satellite;

at least one ground station comprising at least two receiving antennas each said receiving antenna being orientated toward a corresponding one of said at least two satellites to receive transponded signals transmitted from said corresponding satellite to said ground station;

a diversity receiver at said at least one ground station for jointly processing transponded signals transmitted from said at least two satellites and received by said at least two receiving antennas to decode information transmitted by said mobile communications terminals.

27. The system of claim 26 wherein said multi-element satellite antennas for each of said orbiting satellites are Direct Radiating Arrays comprised of dual-polarization array elements.

28. The system of claim 26 wherein said multi-element satellite antennas for each of said orbiting satellites comprise multiple dual-polarization antenna feed elements and a reflector.

29. The system of claim 28 wherein respective ones of said multiple dual-polarization antenna feed elements are located out of the focal plane of said reflector.

30. The system of claim 28 wherein respective ones of said multiple dual-polarization antenna feed elements are coupled using a Butler matrix.

31. The system of claim 29 wherein selected subgroups of each of said multiple dual-polarization antenna feed elements are coupled using Butler matrices of reduced complexity.

32. The system of claim 26 wherein each of said dual channel transponders uses quadrature time division multiplexing to preserve relative phase and amplitude between signals from different satellite antenna elements of the same satellite.

33. The system of claim 26 wherein said diversity receiver comprises:

a plurality of demultiplexers for separating signals received from each satellite into separate signals corresponding to different satellite antenna elements; and

a plurality of channelizers for further separating each of said separated signals by frequency channel to obtain channelized signals.

34. The system of claim 33 further comprising a plurality of beamformers for each of said frequency channels to combine ones of said channelized signals corresponding to the same frequency channel to obtain beamformed signals.

35. The system of claim 34 further comprising a plurality of diversity demodulators for combining ones of said beamformed signals corresponding to the same frequency channel and beam direction but different satellites to decode information transmitted by said mobile communications terminals.

36. A communications satellite system having at least one satellite for providing communications between at least one of a plurality of mobile terminals and one of at least two ground stations, said at least one satellite comprising:

a plurality of feeder link antennas that receive feeder link signals from said at least two ground stations;

a separate demultiplexer connected to each feeder link antenna that demultiplexes each feeder link signal to obtain power amplifier drive signals;

a plurality of combiners that combine power amplifier drive signals corresponding to the same power amplifier but received from different ones of said ground stations to obtain combined drive signals;

power amplifiers that amplify corresponding combined drive signals to obtain transmit signals; and

a multi-element transmitting antenna coupled to said power amplifiers that transmits said transmit signals so as to form directive transmission beams in multiple directions for communicating information to said plurality of mobile terminals.

37. The system of claim 36 wherein said multi-element transmitting antenna is a Direct Radiating Array with each radiating element coupled one-for-one to a corresponding one of said power amplifiers.

38. The system of claim 36 wherein said multi-element transmitting antenna comprises multiple antenna feeds and a reflector, said multiple antenna feeds being coupled to said power amplifiers using at least one Butler matrix.

39. The system of claim 38 wherein said multiple antenna feeds are located out of the focal plane of said reflector.

40. The system of claim 36 wherein said plurality of combiners comprise:

a plurality of up-converters that upconvert each one of said demultiplexed power amplifier drive signals to a transmit frequency band which is the same for all power amplifier drive signals originating from the same ground station and different for power amplifier drive signals originating from different ground stations; and

a plurality of signal adders that add upconverted signals that correspond to drive signals for the same power amplifier to obtain said combined drive signals.

41. A communications satellite system having at least one satellite for providing communications between at least one of a plurality of mobile terminals and one of at least two ground stations, said at least one satellite comprising:

a feeder link antenna for receiving feeder link signals from said at least two ground stations;

a downconverter for downconverting said received feeder link signals to the complex baseband comprising an Inphase (I) signal and a Quadrature (Q) signal;

quadrature demultiplexer for demultiplexing said I and Q signals to obtain demultiplexed signals corresponding to a synchronization channel and a plurality of power amplifier drive signal channels;

a synchronization processor for processing the demultiplexed signal corresponding to said synchronization channel to determine timing errors for signals received from each of said ground stations; and

a feeder link transmitter for transmitting said timing errors to said ground stations such that each ground station may correct its respective timing error by advancing or retarding its transmit timing.

42. The communications system of claim 41 further comprising:

up-converters for upconverting each of said power amplifier drive signals to a frequency band for transmitting to said mobile communications terminals to obtain upconverted drive signals;

power amplifiers for amplifying a corresponding upconverted drive signal to obtain a transmit signal; and

a multi-element antenna, coupled to said power amplifiers, for transmitting said transmit signals such that multiple directive transmission beams are formed for communicating signals to said mobile communications terminals.

43. The system of claim 42 wherein said multi-element antenna is a Direct Radiating Array having a plurality of radiating elements coupled one-for-one with corresponding ones of said power amplifiers.

44. The system of claim 42 wherein said multi-element antenna comprises multiple antenna feeds and a reflector, said multiple antenna feeds being coupled to said power amplifiers using at least one Butler matrix.

45. The system of claim 44 wherein said multiple antenna feeds are located out of the focal plane of said reflector.

46. The system of claim 42 wherein channel frequency components of signals radiated in the same one of said multiple directive beams originating from one of said ground stations are different from channel frequency components of signals radiated at the same time in the same or overlapping beams that originated from a different one of said ground stations.

47. A method for communicating between a plurality of mobile terminals and a plurality of ground stations using at least one orbiting satellite, comprising:

allocating different channel frequencies to ones of said mobile terminals located in such proximity to prevent discrimination between signals transmitted from said mobile terminals and reallocating the same channel frequencies to other ones of said mobile terminals separated by a sufficient distance to allow discrimination between signals transmitted from said mobile terminals;

dividing said plurality of mobile terminals into a plurality of groups and allocating each group to be served by a corresponding ground station;

using beamforming coefficients to form, at each ground station and in dependence on the information to be communicated to the plurality of groups of mobile terminals allocated to be served by the ground station, a set of antenna array drive signals for transmission to said at least one orbiting satellite;

quadrature multiplexing at each of said ground stations the set of antenna drive signals formed at the ground station to form a quadrature multiplexed signal;

upconverting said quadrature multiplexed signals to a feeder link frequency common to all ground stations to obtain a feeder link signal at each ground station;

transmitting said feeder link signals from each ground station to said at least one orbiting satellite;

receiving at said satellite the overlapping sum of said feeder link signals from said second plurality of ground stations;

quadrature demultiplexing said received sum of feeder link signals to obtain reconstructed antenna array drive signals; and

using said reconstructed antenna array drive signals to form corresponding amplified transmit signals for a multi-element transmit antenna on said at least one satellite such that said transmit antenna radiates signals to each of said plurality of mobile terminals in a corresponding directive beam, each signal having originated from the ground station allocated to serve the corresponding mobile terminal and each corresponding beam direction being under the control of the allocated ground station by choice of said beamforming coefficients.

48. The method of claim 47, further comprising synchronizing said quadrature multiplexing at each ground station to said quadrature demultiplexing on board said at least one orbiting satellite.

49. The method of claim 48 wherein said synchronizing said quadrature multiplexing at each ground station to said quadrature demultiplexing on board said at least one orbiting satellite is achieved by using a timing error feedback signal received from said at least one orbiting satellite.

50. A method of transmitting signals from a ground station to a satellite for transmission using a multi-beam antenna, comprising:

assembling a sample of each signal to be transmitted using different ones of said multiple antenna beams into a vector;

performing an orthogonal transformation of the vector to obtain a transformed vector;

quadrature multiplexing the elements of the transformed vector to obtain a quadrature multiplex signal;

quadrature modulating the multiplex signal to a feeder link frequency to obtain a feeder link signal and transmitting said feeder link signal to the satellite;

receiving, downconverting and quadrature demultiplexing said feeder link signal at the satellite to obtain power amplifier drive signals;

quadrature modulating the power amplifier drive signals to the frequency for transmission from the satellite and driving a set of power amplifiers with the corresponding quadrature modulated signals; and

coupling the amplified signals from said power amplifiers to the feeds of a multiple-feed reflector antenna using Butler matrices such that an inverse orthogonal transform is performed by the coupling, thereby achieving increased insensitivity to mis-synchronization between said quadrature multiplexing and said quadrature demultiplexing.